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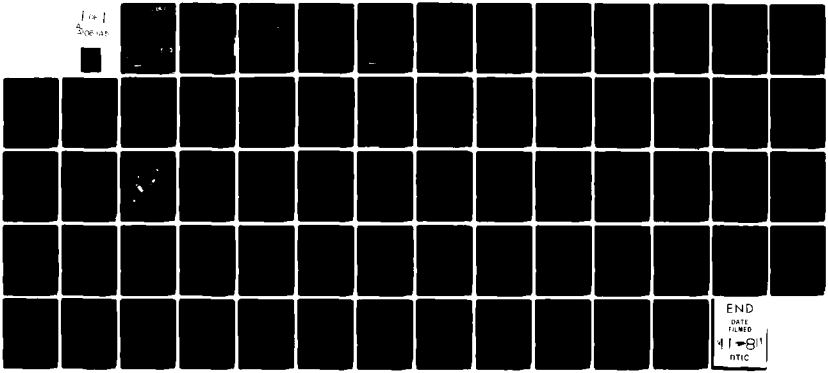

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AN ANALYSIS OF COGNITIVE MAPPING SKILL

Sarah E. Goldin and Perry W. Thorndyke

March 1981

N-1664-ARMY

Prepared For The United States Army

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Compares the performance of good and poor cognitive mappers on a variety of spatial knowledge acquisition and judgment tasks. Cognitive mapping skill was assessed by measuring subjects' knowledge of a highly overlearned environment, their home community. Subjects categorized as good or poor cognitive mappers participated in a series of experiments that examined learning a novel environment from navigation experience, map learning, map using and map interpretation, spatial judgments based on a memorized map, and navigation in a novel environment based on a memorized map. Good mappers performed more accurately than poor mappers in learning a novel environment, learning maps, and making spatial judgments based on a memorized map. Map using, map interpretation, and navigation tasks did not distinguish good from poor mappers. We conclude that, relative to poor mappers, good cognitive mappers are better able to encode and retain spatial information in memory and to mentally transform or manipulate spatial information in order to make spatial judgments, and we hypothesize that differences in spatial visualization and visual memory abilities may underlie these variations in task performance.

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AN ANALYSIS OF COGNITIVE MAPPING SKILL

Sarah E. Goldin and Perry W. Thorndyke

March 1981

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Prepared For

The United States Army

Rand
SANTA MONICA, CA. 90406

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PREFACE

This Note describes a study undertaken at Rand for the Army Research Institute under Contract No. MDA-903-79-C-0549 to investigate individual differences in spatial knowledge acquisition and spatial judgments. The results reported here are further elaborated in companion Rand Note N-1667-ARMY, Ability Differences and Cognitive Mapping Skill. This research should interest both researchers studying human spatial cognition and practitioners concerned with improving individual orientation and navigation skills.

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SUMMARY

This Note compares the performance of good and poor cognitive mappers on a variety of spatial knowledge acquisition and judgment tasks. Cognitive mapping skill was assessed by measuring subjects' knowledge of a highly overlearned environment, their home community. Good cognitive mappers were defined as individuals who performed accurately on orientation judgment, route and straight-line distance estimation, and landmark location tasks. Poor cognitive mappers were identified on the basis of inaccurate performance on these tasks. All subjects participated in a series of experiments that examined learning a novel environment through navigation, map learning, map using and map interpretation, spatial judgments based on a memorized map, and navigation in a novel environment based on a memorized map. Good mappers excelled in learning a novel environment, learning maps, and making spatial judgments based on a memorized map. In contrast, good and poor mappers did not differ on map using, map interpretation, and navigation tasks. We conclude that, relative to poor mappers, good cognitive mappers more readily encode and retain spatial information in memory. Further, they more accurately transform or manipulate spatial information in memory in order to make spatial judgments. We hypothesize that differences in spatial visualization and visual memory abilities, as well as differences in processing strategies, may underlie the variations in task performance associated with cognitive mapping skill.

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Several individuals contributed to preparation of this Note. Jackie Berman and Doris McClure gathered and analyzed the data. Kay McKenzie prepared the manuscript. John Winkler provided useful comments on an earlier draft.

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I. INTRODUCTION

Tasks requiring the use of geographic information play a crucial role in many military operations. Such tasks include planning attack or supply routes, avoiding enemy fire, carrying out reconnaissance, and navigating to a rendezvous point. These tasks involve reading and interpreting maps, navigating according to a preselected route, and orienting and locating oneself in unfamiliar terrain. Mission success may often depend upon the skills of a few key individuals performing these tasks. Thus, it is important to understand the psychological bases of these skills and to develop methods for assessing and training them.

Acquiring an accurate representation of the configuration and location of objects in the environment is a fundamental component in many spatial tasks. The process of developing such a representation is often referred to as cognitive mapping (Downs & Stea, 1973). Much research has documented striking individual differences in cognitive mapping skill. Descriptive studies have demonstrated that individuals vary greatly in their cognitive maps of familiar environments (e.g., Beck & Wood, 1976a, 1976b; Canter, 1977; Carr & Schissler, 1969; Craik & McKechnie, 1977; Lynch, 1960; Milgram & Jodelet, 1975; Rand, 1969). Experimental studies have also investigated individual differences in skills that may play a role in cognitive mapping, including map learning (Thorndyke & Stasz, 1980), navigation and orientation (Kozlowski & Bryant, 1977), and map drawing based on navigation experience (Chase & Chi, 1979).

Researchers have proposed several explanations for these individual differences. One approach argues that individual differences depend on basic abilities. Thorndyke and Stasz (1980; Stasz & Thorndyke, 1980) have shown that the amount of information people learn from a map can be predicted from their visual memory and spatial restructuring abilities. Kozlowski and Bryant (1977) found that subjects' orientation performance in a maze was predictable from their self-rated "sense of direction." A second approach focuses on differences in individuals' exploratory motivation and characteristic mode of environmental interaction. For instance, "rangers," individuals who like to explore alone or in small groups, demonstrate greater cognitive mapping skill than "fixers," who stay close to home, or "mixers," who travel in large, socially oriented groups (Beck & Wood 1976a). A third approach attributes individual differences to the amount or type of environmental experience available to the individual. Individuals with more experience in cities are better cognitive mappers in an unfamiliar city than individuals inexperienced in urban environments (Beck & Wood, 1976a). Conversely, individuals somewhat familiar with natural terrain, such as forests, develop more accurate and complete representations of such environments than inexperienced mappers (Kaplan, 1976). Qualitative aspects of the environmental experience (e.g., mode of transportation, self- versus other-directed travel, environmental exposure via map versus navigation) also influence performance accuracy (Carr & Schissler, 1969; Pezdek & Evans, 1979; Stea, 1976; Thorndyke & Hayes-Roth, 1980). A final approach attributes individual differences to differences in the strategies and procedures people use to perform a task. For example,

Thorndyke and Stasz (1980) found that good map learners employed effective study procedures to isolate and learn spatial information, while poor learners failed to use such procedures.

Despite this work, little is known about the cognitive skills that distinguish good from poor cognitive mappers. Much of the work cited above failed to control the amount and type of individuals' environmental experience. Without such controls, differences in individuals' skill cannot be separated from differences in their familiarity with the tested environments. More controlled studies have used simplified laboratory tasks such as speeded judgments of relative orientation or distance. But these tasks do not capture the richness and complexity of the judgments people make in natural settings. Finally, many cognitive mapping studies have relied on a single measure of the content and accuracy of the environmental representation, such as sketch maps (Lynch, 1960) or orientation judgments (Kozlowski & Bryant, 1977). Single measures may not accurately reflect the extent of an individual's spatial knowledge or skill at using it.

In this Note we examine in detail the skills underlying cognitive mapping. Our general approach is to contrast the performance of people identified as good or poor cognitive mappers on a number of learning and reasoning tasks that utilize information about large-scale space. In making those comparisons, we hope to articulate the task constraints, basic abilities, and processing skills that distinguish individuals with relatively accurate representations of their environment from those with inaccurate representations.

We selected our groups of good and poor cognitive mappers based on their knowledge of the area in which they lived. All subjects had resided on the west side of Los Angeles for at least five years. We assumed that differences in the accuracy of their spatial knowledge about this area indicated asymptotic differences in their skill at abstracting spatial knowledge from navigation experience.

Section II describes in more detail the assessment procedures used to select and classify subjects as good and poor cognitive mappers. Sections III through VII examine the performance of our two subject groups on a number of different spatial tasks: spatial reasoning in a familiar environment based on exposure to both the environment and a map (Experiment 1); knowledge acquisition from maps (Experiment 2); spatial reasoning based on minimal navigation in a novel environment (Experiment 3); map using, including terrain interpretation, object location, route finding, and route following (Experiment 4); and navigation based on a memorized map (Experiment 5). The final section summarizes our conclusions regarding the skills and task competencies that characterize successful cognitive mappers.

II. SELECTION AND EVALUATION OF COGNITIVE MAPPER GROUPS

SUBJECT RECRUITMENT AND DEMOGRAPHICS

The first stage in this research required recruiting a pool of good and poor cognitive mappers. We defined cognitive mapping skill according to subjects' knowledge of a highly familiar, overlearned locale--their own community. To insure that knowledge differences were not due to differences in opportunities to acquire knowledge, we required that all subjects be residents of Brentwood (an area of west Los Angeles comprising approximately 20 square miles) for a minimum of five years. Subjects were recruited through advertisements in local newspapers and were paid 5 dollars per hour for their participation throughout the study. However, most subjects appeared to be motivated primarily by interest in the research and a commitment to participate.

Our initial sample comprised 30 female and 7 male subjects. These individuals had a mean age of 44.8 years (range = 19 to 75) and had lived in Brentwood for a mean time of 16.3 years (range = 5 years to 55 years). Women predominated because many potential male subjects were unavailable to participate in experiments during the day.

ASSESSMENT OF COGNITIVE MAPPING SKILL

We assumed that most subjects had acquired their spatial knowledge of west Los Angeles primarily from navigation. Hence, we used the accuracy of their spatial judgments about west Los Angeles to classify them as good or poor cognitive mappers. People with an accurate representa-

tion of the spatial relations in their community were considered good cognitive mappers, while those with relatively inaccurate representations were considered poor cognitive mappers. This criterion seemed closest to capturing the intuitive meaning of "cognitive mapping skill": the ability to abstract accurate spatial/relational information about an environment from direct experience in that environment.

Subjects completed a preliminary questionnaire assessing their familiarity with a number of west Los Angeles landmarks. Based on their responses to this questionnaire, we selected seven landmarks familiar to all subjects. These landmarks spanned an area of roughly 64 square miles, including all of Brentwood. Each pair of landmarks was at least 2 miles apart. We tested subjects' spatial knowledge on four pencil-and-paper tasks that utilized these landmarks, as described below.

Orientation Judgment

Subjects were presented with a list containing pairs of landmark names. For each pair, subjects imagined standing in a particular "canonical" orientation at the first member of the pair. They then estimated the direction in degrees of the second member of the pair, using a large protractor marked in ten degree intervals. As the 0-degree marking on the protractor always pointed directly in front of the subject, the orientation estimates were made relative to the assumed starting location rather than relative to magnetic north. Twenty-one unique pairings of landmarks were presented. Landmarks served as the "TO" landmark and the "FROM" landmark equal numbers of times. Performance was measured as the mean across items of the absolute angular disparity from the true orientation.

Euclidean Distance Estimation

For the same 21 pairs of landmarks, subjects were asked to estimate the straight-line distance between the members of each pair, to the nearest quarter mile. Subjects were told the distance between two other familiar points in west Los Angeles, to provide a standard use in their estimates. Performance for each subject was measured as the correlation between the 21 estimated distances and actual euclidean distances. We adopted this measure in preference to a percent error measure in order to control for individual differences in the subjective scale upon which estimates were based.

Route Distance Estimation

We defined routes connecting each pair of landmarks, using major, familiar streets. Each route was one that a driver would ordinarily take to go from one location to the other. Subjects were asked to estimate the distance between the two landmarks, to the nearest quarter mile, along the specified route. They were reminded that route distance would always be at least as large as the corresponding euclidean distance. The correlation between estimated and actual route distances served as our measure of performance.

Location Task

Subjects were given sheets of paper with labeled points indicating the locations of two landmarks (the "reference" and "context" landmarks). They were asked to locate a third landmark (the "target" landmark) relative to the reference landmarks, using the context landmark to

establish the scale and orientation of this simple map. The location task comprised 42 items. Each of the seven landmarks served as the target landmark with each of the remaining six landmarks as a reference landmark. Context landmarks for each item were chosen so that each context-target pair appeared only once with a given reference landmark. The location task yielded two measures: the mean absolute angular disparity between the bearing of the subject's response and the true location of the target (relative to the reference and context landmarks) and the mean distance in millimeters from the located point to the true landmark location. Across subjects, these two measures were highly correlated ($r = .65$, $p < .01$).

SELECTION CRITERIA FOR GOOD AND POOR MAPPERS

To obtain an overall measure of each subject's cognitive mapping skill, we devised a composite score based on subjects' angular error on the orientation task, correlation on the estimation task, correlation on the euclidean estimation task, and angular error on the location task. For each task, we rank-ordered subjects according to their accuracy on the task. Each subject's composite score was then the mean of his or her ranks on the four component tasks. Table 1 presents summary statistics for the four tasks and indicates the rank on each task for the subjects with the best and the worst composite scores.

We adopted two selection criteria to assign subjects to the good and poor cognitive mapper groups. A subject was considered to be a good cognitive mapper if he or she (1) scored above the median rank for at least three of the four assessment tests, and (2) scored above the

Table 1

ASSESSMENT TASK PERFORMANCE SUMMARY

Task	Mean Score			Rank[a]	
	Good Mappers	Poor Mappers	All Subjects	Best Overall Subject	Worst Overall Subject
Orientation judgments (degrees error)	42.9	63.6	53.2	6	31
Location judgments (degrees error)	17.0	30.0	23.5	1	28
Route distance estimates (correlation, estimated with actual)	.78	.68	.73	16	31
Euclidean distance estimates (correlation, estimated with actual)	.91	.83	.87	1	31

[a] Rank scores on the individual tasks for the subjects with the best and worst composite rank scores.

median on the composite score. Similarly, individuals were considered poor cognitive mappers if they scored below the median rank on three of the four assessment tests and on the composite score. These criteria classified 12 good cognitive mappers (mean composite score = 10.04) and 12 poor mappers (mean composite score = 21.41). This sample, which included 5 men and 19 women, had a mean age of 39.7 years and had lived in Brentwood for a mean time of 12.9 years.

By restricting the two groups to individuals who consistently showed good or poor performance, we reduced our original sample by more than one-third, from 37 to 24. We felt this was necessary, however, because subjects who scored high on some tasks and low on others were difficult to classify, and we wanted to avoid any ambiguities about the skill of the subjects in our groups. Further, we wished to examine performance differences at the extremes of the performance distribution in order to highlight underlying skill differences.

POSSIBLE CONFOUNDING FACTORS

Having established our subject groups, we wished to rule out potential artifacts influencing performance on our assessment tests. That is, we wanted to determine whether or not the two subject groups differed in any other obvious ways that might explain their performance differences on the assessment tests. Therefore, we compared the two groups on a number of dimensions, including general intellectual ability, memory ability, age, and years of residence in the Brentwood area.

Good mappers did not differ from poor mappers in either age (36.1 years vs. 43.3 years, $t(22) = 1.59$, ns) or number of years of residence in Brentwood (11.6 vs. 14.2 years, $t(22) = 1.00$, ns). Of course, years of residence does not directly measure the quantity of environmental experience. For example, someone who has lived in Brentwood only five years might have traveled in the community more than a resident of 10 years. In addition, we did not assess qualitative differences in environmental experience (e.g., mode of transportation, self- vs. other-guided travel) that influence spatial knowledge acquisition

(Pezdek & Evans, 1979; Stea, 1976). However, if the differences between our two groups on the assessment tasks are actually attributable to some quantitative or qualitative aspect of experience, this artifact should attenuate rather than augment between-group differences on other spatial tasks.

In a separate experimental session, subjects were tested on verbal ability (which correlates highly with IQ and is often used to measure overall intelligence) (e.g., Horn, 1976) and verbal long-term memory. The two groups did not differ in either verbal ability ($t(22) = 1.41$, ns) or verbal memory ($t(22) = 1.64$, ns).

In short, we found no evidence that individual differences in cognitive mapping skill can be attributed to differences in intelligence, memory ability, age, or experience. Thus, we assumed that any between-group performance differences on spatial tasks would reflect differences in skill at processing spatial information.

III. EXPERIMENT 1: PROVIDING SUPPLEMENTARY SURVEY KNOWLEDGE TO GOOD AND POOR MAPPERS

Previous research has suggested that the type of knowledge individuals acquire about an environment depends on the nature of their environmental experience. People acquire procedural knowledge about an environment from navigation experiences (Seigel & White, 1975; Thorndyke, 1980, 1981; Thorndyke & Hayes-Roth, 1980). Such knowledge encodes memories of action sequences required for travel between separate points. Thus, a person learns the relative locations of and distance between two points by noting the direction and distance of the legs on the route connecting them. In contrast, survey knowledge of an environment encodes map-like, global relations among points that are independent of particular routes. Such knowledge encodes interpoint distances and relative locations of objects in a fixed-coordinate system rather than with respect to the motion of an individual in the environment.

Although navigation experience generally leads to procedural knowledge of an environment, extensive experience can lead to the induction of survey knowledge based on abstraction or inference from procedural knowledge. The rate at which survey knowledge can be abstracted from navigation experience varies across individuals (Thorndyke, 1980). Furthermore, while survey knowledge can be induced from procedural knowledge after considerable navigation experience, it is most easily learned directly from a map (Siegel & White, 1975; Thorndyke & Hayes-Roth, 1980).

The type of knowledge people have about an environment has important implications for their performance on spatial tasks. In particular, when people judge the relative location of two objects, or the euclidean distance between them, estimates that are based on survey knowledge are typically more accurate than those based on procedural knowledge. In contrast, when performing orientation judgments and route distance estimates, people are more accurate when they base their estimates on procedural knowledge (Thorndyke & Hayes-Roth, 1980).

This suggests that an important source of differences between good and poor mappers may be their ability to abstract survey knowledge from navigation experiences and construct an accurate "mental map" of the environment. If poor mappers had less developed, less accurate survey knowledge of west Los Angeles, then their performance on the location and euclidean distance tasks would be inferior to that of good mappers. This was in fact what was observed in the assessment study.

In Experiment 1, subjects used a map of west Los Angeles to plan routes among the seven landmarks used on the assessment tasks. By viewing and using the map, subjects had an opportunity to directly acquire survey knowledge about the spatial configuration of the landmarks. If poor mappers possess less developed survey knowledge, the map should reduce or eliminate their performance deficit on tasks requiring survey knowledge (provided they encode and use the available map information). Thus, we should find an interaction between skill group and experiment. Furthermore, this interaction pattern should be most apparent on the euclidean distance estimation and location tasks, rather than on the orientation and route distance estimation tasks.

METHOD

Approximately six weeks after administration of the assessment battery, subjects returned to participate in the experiment. They were given a map of west Los Angeles with the seven landmarks used in the assessment study clearly highlighted. They were instructed to plan and trace an efficient route connecting all seven landmarks. The instructions emphasized that the route should minimize distance and expected travel time. When subjects finished tracing their routes, the maps were collected. Subjects then performed the same spatial judgment tasks used in the assessment study (orientation, landmark location, euclidean and route distance estimation).

RESULTS AND DISCUSSION

We analyzed the results for each type of judgment using a 2 by 2 (mapper group by experiment) analysis of variance. Table 2 summarizes the performance of both groups on the judgment tasks. On each task, the main effect for mapper group yielded a significant F ratio (with 1 and 22 degrees of freedom). Exposure to the map did not eliminate or reduce the difference between good and poor groups. In fact, performance did not improve after viewing the map for either group. More importantly, there were no significant interactions between mapper group and experiment on any of the judgment tasks. This disconfirms our prediction that the difference between good and poor mappers' spatial judgments should decrease when poor mappers are given supplemental survey information.

Poor mappers may have failed to improve their performance after viewing maps for several reasons. First, the incidental learning situa-

Table 2

PERFORMANCE ON SPATIAL JUDGMENT TASKS
BEFORE AND AFTER VIEWING A MAP

Task	Good Mappers		Poor Mappers		
	Before Map	After Map	Before Map	After Map	F ratio[a]
Orientation judgments (degrees error)	42.9	46.7	63.6	61.9	7.84[b]
Location judgments (degrees error)	17.0	17.0	29.9	31.7	10.86[b]
Route distance estimates (correlation, actual with estimated)	.78	.77	.68	.65	16.23[b]
Euclidean distance estimates (correlation, actual with estimated)	.91	.90	.82	.86	10.30[b]

[a] F ratio for mapper group main effect.
[b] $p < .01$.

tion provided by the route-finding task may not have motivated subjects to encode and retain survey knowledge. We had expected that merely exposing subjects to a map would be sufficient to induce survey knowledge. However, explicit instructions to study survey relations may be a necessary condition for learning in this situation. This hypothesis would explain the failure of even good mappers to improve their performance. Second, poor mappers may be deficient in their abil-

ity to encode information from a map and retain it in memory. If this is the case, supplementary information presented in map form would not assist them in their spatial judgments in any significant way. Good mappers, on the other hand, may have failed to improve in their judgments of survey relations because their performance had already approached a ceiling. Third, the inferior performance of poor mappers may result from ineffective or inaccurate spatial reasoning procedures, rather than from inaccurate or incomplete knowledge. Spatial judgments require both a body of spatial knowledge and a set of computational procedures that operate on that knowledge (Thorndyke & Hayes-Roth, 1980). Individual differences could exist in the accuracy of either or both of these components.

In Experiment 2, we evaluated these hypotheses by requiring subjects to learn a map and perform spatial judgments based on their knowledge of the map. If poor mappers are inferior in their ability to acquire knowledge from maps, they should learn more slowly than good mappers. If poor mappers utilize less accurate computational procedures than good mappers, their spatial judgments should be less accurate than those of good mappers even when all subjects possess veridical spatial representations of the environment.

IV. EXPERIMENT 2: THE ACQUISITION OF SPATIAL KNOWLEDGE FROM MAPS

Previous research has demonstrated that individuals differ in map learning skill according to both their visual memory ability and the specific procedures they use to select and encode spatial information from the map (Stasz & Thorndyke, 1980; Thorndyke & Stasz, 1980). However, these studies did not investigate the relationship between map learning skill and skill at acquiring spatial knowledge from direct experience. The present experiment investigates this relationship.

METHOD

Two different maps were used in this study: a simplified map of Australia (shown in Figure 1) and a map of the floor plan of the two buildings of The Rand Corporation (shown in Figure 2). Subjects studied one of the maps for 2 minutes. They then received a sheet of paper with two of the landmarks' positions indicated on it. They were instructed to use these landmarks as points of reference and to sketch around these two points as much of the map as they could recall. Subjects had up to 7 minutes to complete their maps.

For the Australia map, all subjects received five study-test trials. As a control against the possibility that subjects actually had learned more than they were able to express in their sketch maps, we administered a 10-item test of spatial relations following the last trial. These items required either true or false responses (e.g., Lake Eyre is in the same province as Lake MacKay) or the selection of one of two alternatives (e.g., which is closer to Lake MacKay: Great Dividing Range or Lake Disappointment).

Fig. 1--Map of Australia

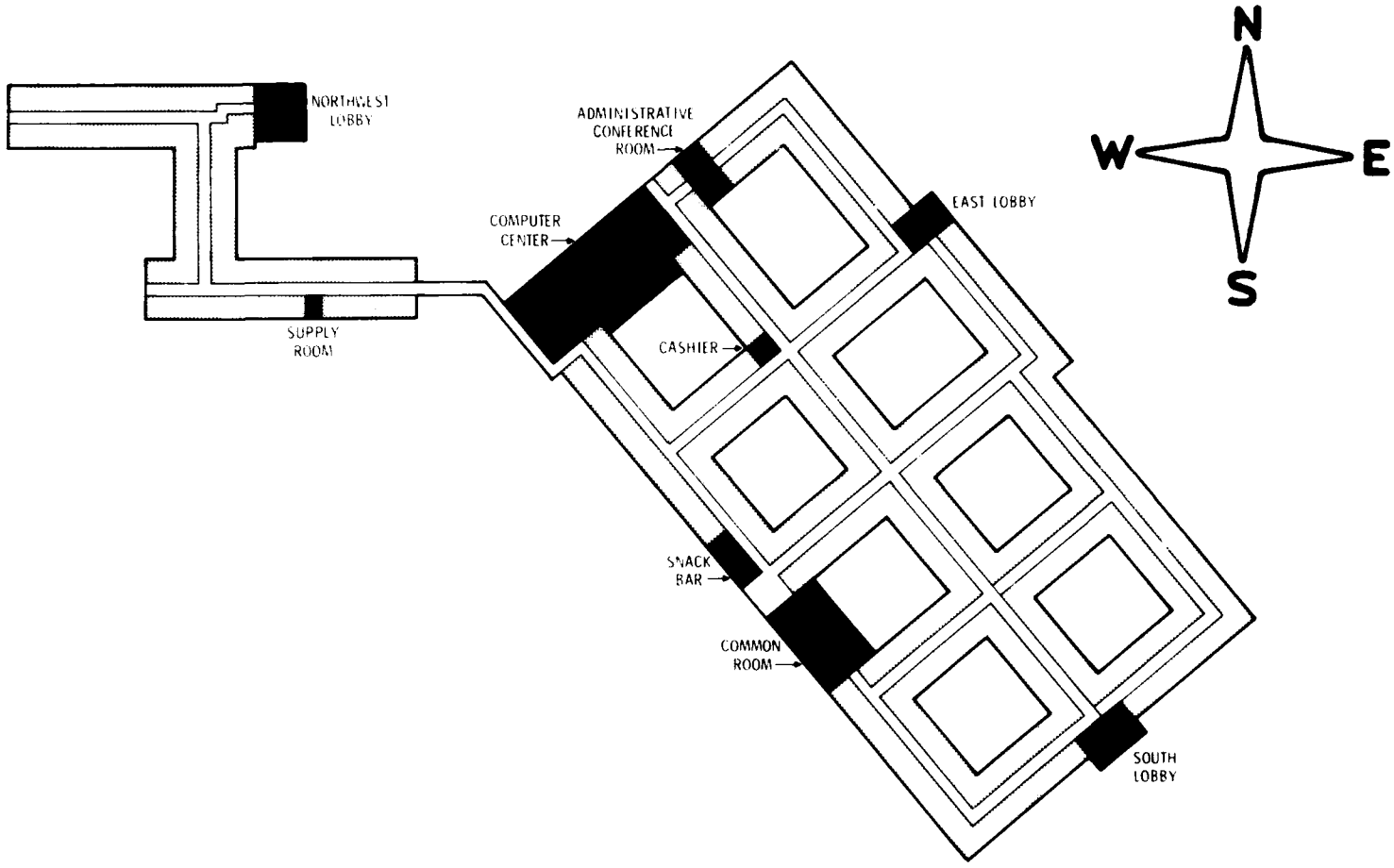

Fig. 2--Floor plan map of Rand buildings

For the Rand map, subjects received as many study-test trials as necessary to learn the entire map. Our learning criterion required that their final map include correct corridor structure for both buildings, a roughly 130 degree jog in the corridor connecting the buildings, and correctly located and labeled landmarks. After reaching criterion on the Rand map, subjects received 21 orientation judgment problems like those used in Experiment 1.

RESULTS

Scoring Procedures

Following the method of Thorndyke and Stasz (1980), we scored each reproduced map for the presence or absence of predefined elements, such as major land features, cities, landmarks, or corridors (for the Rand map). Most elements had both spatial (location and shape) and verbal (name) attributes. These attributes were scored independently. Elements with no verbal labels were scored on the spatial attributes only. The Australia map included 32 elements, 28 of which had verbal labels. The Rand map included 20 elements, 7 of which were labeled.

Maps were scored by one judge, then 10 percent of the maps were selected at random for rescoring by a second judge. The correlations between the scores assigned by the two judges ranged from .95 to 1.00 for the maps in this sample.

We also scored maps for the locational accuracy of recalled elements by using the two given points as a frame of reference defining the

correct location of the other landmarks. Thus, a subject's map could be overlaid on the correct map to determine the distance between the true landmark locations and the subject's recalled locations (measured in millimeters).

The map learning tasks provided several types of data: percent correct verbal attributes, spatial attributes, and total elements for each trial; location error scores for each trial; performance on the ten-item test (Australia map); angular disparity scores on the orientation task (Rand map); and trials to criterion (Rand map).

The results of all analyses are summarized in Table 3 and discussed below.

Individual Differences in Learning Performance

The percent correct spatial attributes, percent correct verbal attributes, and percent correct total elements (i.e., both verbal and spatial attributes correct) for the Australia map were each analyzed using a 2 (mapper groups) by 5 (trials) analysis of variance.

On the Australia map, good cognitive mappers tended to perform better than poor mappers in acquiring map information. Overall, good mappers recalled slightly more verbal attributes than poor mappers ($F(1,21) = 5.96$, $p < .03$); and the advantage of good over poor mappers in recall of spatial attributes and recall of complete elements was even more pronounced ($F(1,21) = 8.14$, $p < .01$, and $F(1,21) = 7.87$, $p = .01$, respectively). In all three analyses, the effects of trials were highly significant and there was no interaction between groups and trials. Thus, the results from the Australia map suggest that good cognitive

Table 3

PERFORMANCE OF GOOD AND POOR MAPPERS ON MAP LEARNING TASKS IN EXPERIMENT 2

Task	Good Mappers	Poor Mappers	*t* or *F* value
Australia Map			
Mean percent total elements	17.8	11.8	7.87[b]
Trial 1	6.2	3.0	
Trial 2	15.4	9.0	
Trial 3	20.0	13.9	
Trial 4	22.2	16.5	
Trial 5	25.1	16.8	
Question answering (% correct)	84.2	76.7	1.65
Landmark location error (millimeters)	1.17	1.58	2.25[a]
Rand Map			
Mean percent total elements	21.5	17.5	.94
Percent total, Trial 1	17.0	12.5	
Percent total, Trial 2	26.0	22.5	
Landmark location error (millimeters)	1.25	1.23	.10
Trials to criterion	3.3	3.6	.57
Orientation error (degrees)	25.1	37.8	2.96[b]

[a] $p < .05$.
[b] $p < .01$.

mappers have an overall advantage in learning map information obtained on the first study trial, and that this advantage is especially pronounced for the spatial aspects of a map (e.g., placement of landmarks, shape and location of landforms). However, there is no evidence suggesting that good mappers learn faster than poor mappers; their learning rates are essentially the same after the first trial.

The analyses of learning performance on the Rand map were also subjected to a mapper-group-by-trial analysis of variance. Since subjects received different numbers of trials on this map, the analysis included only the first two trials, the minimum number needed by any subject to reach criterion. On the Rand map, good mappers recalled more than poor mappers on every trial. However, none of the three analyses (verbal attributes, spatial attributes, complete elements) yielded a significant effect of group or a group-by-trials interaction. Further, the groups did not differ in the number of trials required to reach criterion ($t(22) = .55$, ns). The Rand map had fewer elements than the Australia map, and most of them were located in a rectilinear grid (i.e., the Rand building with parallel and perpendicular corridors). The relative simplicity of this map may have attenuated differences between groups. These differences may be most pronounced when the learning task requires encoding a large amount of poorly structured spatial information.

Individual Differences in Landmark Location Accuracy

The measures of the proportion of map information recalled assess the quantity of information subjects encoded, but they indicate only roughly the accuracy of spatial knowledge. By measuring the average

distance from subjects' landmark placements to the true locations of the landmarks, we could derive a more sensitive measure of locational accuracy. Good mappers were more accurate in their placement of landmarks on their maps of Australia (mean distance = 1.17 mm) than poor mappers (mean distance = 1.58 mm) ($t(22) = 2.25$, $p < .05$). This difference cannot be attributed to differences in drawing ability. Good mappers also answered the multiple-choice questions more accurately than the poor mappers (84 percent vs. 77 percent), although this difference was unreliable. However, performance on this task was significantly correlated with locational accuracy ($r = -.49$, $p < .01$).[1] Thus, the location accuracy scores appear to reflect differences in detailed survey knowledge rather than differences in drawing ability.

Individual Differences in Computational Accuracy

As noted above, performance differences in the assessment study could be attributed to differences in the accuracy of the spatial representation and/or differences in the accuracy of computational procedures that operate on that representation to produce spatial judgments. To demonstrate differences in computational accuracy, it is necessary to control for the accuracy of the available knowledge. Since all subjects learned the Rand map to the same criterion, orientation judgments should reflect the relative accuracy of computational procedures with knowledge held more or less constant. As the last row in Table 3 shows, good mappers performed more accurately on the orientation

[1] The negative correlation reflects the fact that better question-answering performance is associated with smaller distance errors.

task than poor mappers ($t(22) = 2.83$, $p < .01$). Thus, good mappers seem to excel not only in acquiring spatial knowledge, but also in using that knowledge to perform spatial judgments.

DISCUSSION

Individuals who excel at abstracting spatial relationships from direct experience also appear to excel at map learning. Every obtained difference in map learning performance favored the good over the poor cognitive mappers.

These results correspond to the differences obtained by Thorndyke and Stasz (1980) in their comparison of subjects with high and low visual memory ability. Subjects of different ability varied in their recall of spatial attributes and complete elements, but not in recall of verbal attributes. In the present study, group differences were also smallest in recall of verbal information from the maps. Thorndyke and Stasz found large intergroup differences in the use of procedures for encoding spatial information, such as visual imagery. These procedures are particularly useful for learning irregular shapes and spatial relationships that are difficult to encode verbally. In the present study, the superiority of the good mappers was most prominent on the map with the more complex and irregular configuration of spatial attributes.

The failure of the Rand map to yield significant group differences may be due to the relative simplicity of this map. Because it contained few elements and a regular grid of corridors, it may have been too easy to tax the poor mappers' skills. Indeed, many subjects required only two or three 2-minute study trials to learn the map perfectly. To

determine whether or not differences in learning rate existed among subjects for whom this task was not overly simple, we reanalyzed the spatial attribute recall data, including only subjects who required four or more trials to reach criterion. There were seven such subjects in each of the mapper groups. This analysis, which followed a 2 (mapper groups) by 4 (trials) design, yielded a marginal effect of mapper group ($F(1,12) = 3.86$, $p < .08$) and a marginal interaction of group by trials ($F(3,36) = 3.73$, $p < .02$), both favoring the good mapper group. Thus, disregarding subjects who learned this map with relative ease, there appears to be some evidence that good mappers outperformed poor mappers in learning the Rand map as well as the Australia map.

The results of this study suggest several new distinctions between good and poor mappers. First, the meaning of "good cognitive mapper" extends beyond tasks that require learning spatial information from direct experience. Good mappers may perform better on any task that requires the acquisition of knowledge about large-scale space, regardless of the source of that knowledge. Second, poor mappers' failure to benefit from supplementary map information in Experiment 1 may have derived from their inability to encode and retain the map information. Third, the results of the orientation task indicate that poor mappers also use relatively inaccurate or unreliable computational procedures to produce their spatial judgments. This fact may also have contributed to the deficit shown by poor cognitive mappers in the first two studies.

In the assessment study and Experiment 1, good and poor mappers differed in their spatial judgments after extensive exposure to the environment. These differences appeared in tasks measuring <u>both</u> pro-

cedural and survey knowledge. In Experiment 2, after even a single exposure to a source of survey information (the Australia map), good and poor mappers differed in the knowledge they acquired (see Table 3). Given these results, comparable differences might be expected to occur in the initial stages of procedural knowledge acquisition. The next experiment examines this hypothesis.

Even if good and poor mappers initially acquire procedural knowledge at equivalent rates, their spatial judgment performance may still differ. The results of the Rand orientation judgments suggest that good mappers use more accurate computational procedures than poor mappers. If this is the case, good mappers should excel in spatial judgment tasks at all stages of learning.

V. EXPERIMENT 3: THE ACQUISITION OF SPATIAL KNOWLEDGE FROM LIMITED NAVIGATION

In Experiment 3, we provided subjects with a map and a single trip through a large-scale, real-world environment as a source of both procedural and survey knowledge. We then tested the accuracy of their spatial knowledge about that environment. We expected to obtain performance differences between mapper groups, even with such limited exposure to the environment.

METHOD

Experimental Environment

A circuitous route approximately 4 miles long in an area of west Los Angeles that was unfamiliar to the subjects served as the experimental environment. The route followed winding, irregular streets through a residential area. Seven locations along the route were chosen as landmarks. Each landmark possessed some salient feature that was used as its distinguishing label (e.g., brown cinder-block house, Tudor house). Maps of the area were prepared by marking an official street map of west Los Angeles with the route and landmarks (Thomas Bros., 1969, Segment 41).

Procedure

Subjects met the experimenter at a prearranged location that was, in fact, the starting point of the experimental route. Each subject was given a map and a set of multiple-choice questions, each of which asked about a detail of one of the landmarks. This procedure was designed to

focus subjects' attention on the landmarks. Subjects were also instructed to learn the route and the spatial relations among landmarks. They were told to report back to the experimenter upon reaching the end of the route (which was the same as the starting point). Upon their return, subjects received several tests of their spatial knowledge, similar to those used in the assessment study, as follows.

Orientation Judgment. Subjects imagined standing in a specified position at each of the landmarks and pointing in the direction of each of the other landmarks. Mean absolute angular disparity served as our performance measure.

Euclidean Distance Estimation. Subjects estimated straight-line distances among landmarks, as in the earlier experiments. The correlation between actual distance and estimated distance served as our performance measure.

Route Distance Estimation. Subjects estimated the distance between landmarks along the route that they had traveled. A standard distance was supplied to help them calibrate their estimates. The correlation between actual and estimated distances served as our performance measure.

Map-Drawing (Location) Task. Subjects were given a blank sheet with two points specified: the first landmark and another nearby location familiar to all subjects. They were instructed to draw a map of the experimental route, including all landmarks at the correct distance and angular relationship to the two specified points. The mean distance in millimeters between the located landmarks and their true locations served as our performance measure.

A composite performance score was computed for each subject by taking the mean of the subject's ranks on four judgment tasks.

RESULTS AND DISCUSSION

Table 4 presents group means for the four tasks and the combined rank score. Good mappers performed significantly better than poor mappers on the orientation and euclidean distance estimation tasks. On the route estimation task, the superior performance of good mappers was marginally reliable. The groups did not differ in their performance on the location task.

Table 4

PERFORMANCE ON SPATIAL JUDGMENT TASKS AFTER A SINGLE ENVIRONMENTAL EXPOSURE IN EXPERIMENT 3

Task	Good Mappers	Poor Mappers	t value
Orientation (angular error)	37.7	61.1	3.16[a]
Location (angular error)	21.9	21.7	.05
Route distance estimates (correlation)	.75	.63	2.00[b]
Euclidean distance estimates (correlation)	.55	.36	3.04[a]
Mean rank score	12.9	19.0	3.52[a]

[a] $p < .01$.
[b] $p < .10$.

Subjects' composite rank scores in this study were correlated with their composite scores from the original assessment battery (r = .67, p < .01). Other correlations between tasks in this study and the assessment tasks are presented in Table 5. Many of these correlations are significant, and almost all indicate a direct relationship between good performance on assessment tasks and good performance on the tasks in this experiment.[1] This suggests that good mappers possess more accurate representations of an environment at all stages of learning. These results also indicate that the differences between good and poor mappers observed in the assessment study derived from differences in mapping skill and not from qualitative or quantitative differences in experience in the west Los Angeles area.

Combining these data with those from our earlier studies, we can draw some tentative conclusions about the skills that distinguish good mapers from poor mappers. In the present experiment, subjects had available information both from direct experience and from a map. Hence, the superiority of good mappers could stem from several sources.

First, good mappers are better than poor mappers at encoding and using procedural knowledge. Navigating along the prescribed route provided direct information about route distances, changes of direction, and topographical variation. Thorndyke and Hayes-Roth (1980) have

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[1] Some of the negative correlations in Table 5 are due to the direction of performance scales for different measures. Orientation and location task measures were error scores, so that smaller scores indicate better performance. Distance estimation scores were correlations, so that larger scores indicate better performance. Thus the -.42 correlation of route distance with orientation scores for the assessment battery indicates that higher distance estimation accuracy was associated with lower orientation errors.

Table 5

INTERCORRELATIONS AMONG SPATIAL JUDGMENT TASKS IN ASSESSMENT STUDY AND EXPERIMENT 3

	O_1	L_1	R_1	E_1	C_1	O_2	L_2	R_2	E_2	C_2
Assessment										
Orientation (O_1)	--									
Location (L_1)	.60[a]	--								
Route distance (R_1)	-.42[b]	-.39	--							
Euclidean distance (E_1)	-.45[b]	-.07	.46[b]	--						
Composite rank (C_1)	.78[a]	.61[a]	-.74[a]	-.49[a]	--					
Experiment 3										
Orientation (O_2)	.46[b]	.75[a]	-.52[a]	-.15	.58[a]	--				
Location (L_2)	-.02	-.12	.14	.02	-.12	-.21	--			
Route distance (R_2)	-.36	-.03	-.03	.35	-.37	-.07	.26	--		
Euclidean distance (E_2)	-.47[a]	-.32	.52[a]	.57[a]	-.67[a]	-.30	-.02	.28	--	
Composite rank (C_2)	.60[a]	.35	-.42[b]	-.49	.67[a]	.43[b]	.27	-.53[a]	-.79[a]	--

[a] $p < .01$.
[b] $p < .05$.

argued that such procedural knowledge is optimal for use in computing orientation judgments, since the orientation task requires a response that maintains the same horizontal perspective on the world as that in which the acquired knowledge is represented. Because the use of such knowledge entails simpler computational procedures and produces more accurate estimates than the use of survey (map) knowledge, it is reasonable to assume that subjects use this knowledge to produce their orientation estimates. If good mappers excel at encoding and using this type

of knowledge, they should produce more accurate orientation estimates than poor mappers. In fact, we obtained large and reliable differences between groups in the orientation task. Thus, good mappers appear to be superior at acquiring and using procedural knowledge.

Second, good mappers are better at acquiring and using survey knowledge from a map. The map that subjects used while navigating provided survey knowledge not directly available from their navigation experience. As Thorndyke and Hayes-Roth (1980) argue, the use of survey knowledge acquired from a map entails simpler computational procedures and produces more accurate judgments of euclidean distance and object location than the use of procedural knowledge. Although the two map groups did not differ in the accuracy of their landmark placements on the map-drawing task, the good mappers were reliably more accurate than the poor mappers on their euclidean distance estimates. In addition, Experiment 2 demonstrated the superiority of good mappers over poor mappers both in acquiring knowledge from maps and in using survey knowledge to compute orientation judgments. Taken together, these data indicate that good mappers make better use of the survey knowledge available from maps than poor mappers.

Despite the apparent consistency of the superior learning performance of good mappers, another factor may have contributed to the performance differences in Experiments 2 and 3. Rather than being superior learners, good mappers might differ from poor mappers primarily in their ability to read and comprehend maps and interpret map symbols. If good mappers were more familiar with and proficient at using maps than poor mappers, they might find it easier to encode information from them (as

in Experiment 2) and correlate map symbols and locations with environmental cues (as in Experiment 3). In Experiment 4, we test the hypothesis that good and poor mappers differ in their ability to read and use a variety of types of maps.

VI. EXPERIMENT 4: MAP READING AND INTERPRETATION

Reading and using maps requires a special set of conceptual and perceptual skills. An effective map reader must search a complex visual field rapidly and efficiently, recognize and interpret map symbols and scale information, ignore irrelevant information while visually tracing a path through a complex network, and visualize or apprehend three-dimensional terrain properties from a two-dimensional map portrayal.

At least some of these skills are necessary components in the process of learning a map as well (Thorndyke & Stasz, 1980). Since good cognitive mappers encode spatial information from a map more rapidly than poor mappers, they may also excel at some or all of these map interpretation skills. On the other hand, good and poor mappers may differ only in their skill at encoding spatial information and using their knowledge to compute spatial judgments from memory. If this is the case, then good and poor mappers might not differ in their map-using skill or in their ability to learn new map-using skills. Experiment 4 evaluated these hypotheses.

METHOD

Materials

We used two types of maps as experimental materials: conventional road maps and topographic maps portraying terrain relief, such as those commonly used by backpackers or military personnel. The road maps included a map of Sicily showing major cities and highways and a map

of the highway system in western Ohio and eastern Indiana. The topographic maps and tests were adapted from a test developed by the Army Research Institute to assess the map-using skills of Army personnel (Potash, Farrell, & Jeffrey, 1979).

Procedure: Conventional Maps

Subjects performed three different tasks using the Sicily and Ohio maps: place location, route finding, and direction following. Subjects were given copies of the two maps and a booklet of instructions and tests. They completed the three tasks described below, using the Sicily map and then the Ohio map.

On the place location task, subjects read the name of a target to be found (a city or landmark) and two constraints on the location of the target (e.g., Inland northwest of Catania; on Route 117). They were instructed to locate and circle the target on the map as quickly as possible. Each subject located eight targets on each map. Since 23 of the 24 subjects performed perfectly on this task, we used mean time to locate a target as our dependent variable.

On the route finding task, subjects read a pair of location names used on the previous location task and indicated on the map the most direct route between them. They were told to consider a "direct" route as one that had as few turns or road changes as possible and that used major streets or highways whenever possible. Mean time to complete the four items for each map served as the performance measure.

On the direction following task, subjects read a route description specifying a starting point and a set of directions. The description

ended with the question, "Where are you?" For example, one item read, "Start at Randazzo. Go east on 120 to 114. Turn south on 114. Follow 114 to Siracusa. Go west on 124 out of Siracusa. Stop at the first town. Where are you?". Subjects were instructed to trace on the map the route specified by the directions and to write the correct answer to the final question. Subjects performed two such tasks on each map. Mean completion time served as the dependent variable.

Procedure: Topographic Maps

After completing the conventional map tests, subjects worked on the topographic map tests. They were given a booklet that contained instructions and four tests: landform identification, ridge/valley identification, slope identification, and terrain visualization. Subjects first read the introductory instructional material explaining topographic map symbology and contour interpretation. This material included illustrative examples to help subjects learn the rudiments of topographic map interpretation. Subjects then worked through the tests, as described below. For each test, subjects recorded their answers on a separate sheet along with their starting and finishing times for each test item.

On the landform identification test, subjects viewed a topographic map segment marked with four points labeled A through D. For each lettered point, subjects indicated whether the landform at that point was (a) a hill or mountain, (b) a valley or draw, (c) a saddle, (d) a spur, or (e) a depression. This test included two map segments with four labeled points each, for a total of eight items.

For the ridge/valley identification test, subjects viewed a map segment marked with several lettered lines. For each line, subjects indicated whether the line lay (a) along a ridge, (b) along the floor of a valley, or (c) along some other type of terrain. This test comprised eight items contained on a single map segment.

On the slope identification test, subjects viewed map segments each containing four arrows labeled A through D. Each arrow traversed a hill represented on the map. Subjects indicated for each lettered arrow whether the shape of the hill was (a) concave (steeper at the top than at the bottom), (b) convex (steeper at the bottom than at the top), or (c) of uniform slope. They also indicated whether the arrow pointed uphill or downhill. Thus, each problem allowed six response alternatives. This test comprised two map segments, each with four lettered arrows, for a total of eight items.

On the terrain visualization test, subjects viewed map segments, each marked with four arrows labeled A through D. Roughly 1 centimeter from the head of the arrow in the direction indicated by the arrow was a dot. Each map segment was accompanied by a line drawing of a landscape profile showing hills, ridges, draws, etc. Somewhere on this landscape drawing an "X" was marked. Subjects were instructed to choose the arrow that would afford the view indicated in the landscape sketch if an observer stood at the tail of the arrow and looked in the direction indicated by the head of the arrow toward the point indicated by the dot. This dot indicated a point in the terrain that should match the "X" on the landscape sketch. This test comprised eight problems, each of which used a different map segment and landscape sketch.

For each task, we recorded both performance accuracy and problem completion time.

RESULTS AND DISCUSSION

A preliminary analysis of variance on the data from the three tasks using the road maps indicated a main effect of map (the Sicily map was easier than the Ohio map) but no interaction with task or subject group. Therefore, we combined the data for the two maps for subsequent analyses.

Table 6 summarizes the performance of good and poor mappers on each task. As indicated above, virtually all subjects performed the tasks using road maps without error. As Table 6 shows, the groups differed reliably on their speed on the route finding task ($t(22) = 2.52$, $p < .05$). On the terrain interpretation tasks, subjects did not differ on either their accuracy or speed. Although good mappers tend to perform slightly better on many of the tasks, there is no reliable indication that good cognitive mappers are more "fluent" at map reading. Rather, they appear to extract information from a map at the same rate as poor mappers.

To examine the relationship among subjects' performance on the map reading tasks, we computed correlations among the set of dependent variables. Table 7 presents these correlations.

Table 7 suggests that there may be some common skills determining map-using speed, since the speed measures for standard and topographic tasks correlated marginally ($r = .35$, $p < .10$). By and large, however, correlations among accuracy measures fail to achieve significance,

Table 6

PERFORMANCE ON MAP READING AND MAP INTERPRETATION TASKS IN EXPERIMENT 4

Task	Good Mappers	Poor Mappers	t value
Conventional Maps			
Locating places (sec)	43.7	57.1	1.65
Finding routes (sec)	41.1	56.8	2.52[a]
Following directions (sec)	106.0	126.0	1.39
Topographic Maps			
Landform identification			
Time (sec)	126.9	191.5	1.61
Accuracy (% correct)	77.1	59.3	1.85
Slope identification			
Time (sec)	179.6	170.0	.26
Accuracy (% correct)	52.0	42.7	.89
Ridge/valley identification			
Time (sec)	198.8	210.2	.33
Accuracy (% correct)	34.3	46.9	1.50
Terrain interpretation			
Time (sec)	79.0	74.3	.48
Accuracy (% correct)	31.3	32.4	.11

[a] $p < .05$.

Table 7

INTERCORRELATIONS AMONG MAP USING TASKS
IN EXPERIMENT 4

Tasks	CT	TT	%L	%S	%R	%T
Conventional maps						
Time (CT)	--					
Topographic maps						
Time (TT)	.35	--				
Landform identification						
% correct (%L)	-.13	-.07	--			
Slope identification						
% correct (%S)	-.25	-.38	.48[a]	--		
Ridge/valley identification						
% correct (%R)	.23	.24	.17	.06	--	
Terrain visualization						
% correct (%T)	.00	.09	.38	.36	.29	--

[a] $p < .05$.

although all are positive. This suggests that a variety of skills are required for the different tasks, and that skill at one type of map interpretation does not necessarily transfer to other map interpretation tasks.

These data fail to establish clear differences between good and poor mappers in either speed or accuracy of using conventional road maps. The road maps used in this experiment were similar to those subjects tried to learn or used to navigate in Experiments 2 and 3. While those experiments established clear performance differences between good and poor mappers, the present data indicate that poor mappers are not inferior in their ability to perceive or extract spatial information or use maps. These map-using tasks seem to rely heavily on perceptual processes such as scanning and segmentation, and much less on encoding

and memory processes. To account for the subject differences in our earlier experiments, we must assume that the differences lie in the processes by which spatial information from maps and navigation is encoded. Considered in a traditional psychometric framework, our results suggest that good and poor mappers would differ primarily in visual memory ability but not in abilities that require rapid scanning and search in a perceptual field. Indeed, there is some evidence that both good and poor cognitive mappers and good and poor map learners differ in their ability to encode spatial information (Thorndyke & Goldin, forthcoming; Stasz & Thorndyke, 1980; Thorndyke & Stasz, 1980).

A second important result of this study was that good mappers did not differ from poor mappers on the topographic map-using tasks. These tasks required subjects to learn meanings for novel spatial forms (patterns of contour lines) and solve problems using this new spatial knowledge. The instruction provided to the subjects and the problems they solved were simple in comparison to problems of topographic map use and navigation that occur in real-world situations. Nevertheless, our results suggest that the ability to learn maps and to acquire an accurate spatial representation from navigation may be independent of the ability to learn topographic map use and terrain interpretation. These latter skills appear to depend primarily on knowledge of the meaning of particular patterns and contour lines and the ability to visualize the three-dimensional forms represented by the contour depictions (Simutis and Barsam, 1981).

Experiment 4 led to a distinction between skill at acquiring knowledge from maps and skill at using maps to answer questions or solve

problems. In Experiment 5, we consider another task in which subjects use their acquired knowledge to reason about the environment--navigation to a series of destinations.

VII. EXPERIMENT 5: NAVIGATION USING A MEMORIZED MAP

Perhaps the primary reason for attempting to acquire spatial knowledge of a novel environment is to navigate in that environment. Thus far, we have investigated differences between good and poor mappers in their skill at acquiring knowledge and making judgments based on this knowledge. In the current experiment, we examined the performance of our good and poor mappers on a navigation task that utilized newly acquired survey knowledge. Subjects learned a map of a novel environment (the interior of the Rand buildings) and then were asked to navigate a route connecting a particular sequence of landmarks. Time to traverse the route and the distance covered by the route they selected served as our measures of navigation skill.

This task demands that the subjects retrieve knowledge from their mental representation of the environment, acquired from a two-dimensional map, and coordinate it with immediately available cues from the three-dimensional environment. Thus, this task is similar to the terrain visualization of the previous experiment. Good and poor mappers did not differ on the topographic tasks; hence they might perform equally well on the navigation task when using equally accurate stored representations of the environment.

METHOD

After learning the Rand map to the criterion discussed in Section IV, subjects were led to a starting point just outside the Northwest Lobby (see Figure 2). One at a time, they were asked to select and

traverse on foot the shortest route that passed the following five locations: the Cashier, the Administrative Conference Room, the East Lobby, the South Lobby, and the Snack Bar. Half of the subjects were given the landmarks in this order, while the other half were given the reverse order. After reaching the last destination, subjects were to return immediately to the Northwest Lobby. To insure that subjects actually reached each landmark, they were given a set of multiple-choice questions concerning the physical features of each location. Subjects were instructed to complete the tour as quickly as possible at their normal walking speeds. They were told that their overall tour time would be recorded. The experimenter unobtrusively recorded the time required for each subject to walk down the first long hall on the route. This time provided a baseline measure of subjects' walking speed for use in normalizing overall route traversal times. When subjects returned from their tour, they were asked to trace their routes (including all incorrect turns) on a map of Rand. The length of their traced route provided a second measure of navigation effectiveness.

RESULTS AND DISCUSSION

Normalized navigation time (time for the entire tour divided by time to walk the standard distance) served as our principal measure of navigation effectiveness. We assumed that subjects with relatively long navigation times, relative to their own walking speed, were either committing errors in selecting the best route or were having difficulty recalling from memory the knowledge they needed to navigate through the halls. Table 8 shows the mean navigation times and route distances for

good and poor subjects. As Table 8 shows, the two groups did not differ in their normalized walking time. Further, the length of the selected routes did not differ between groups, as shown in the second row of Table 8.

While these data fail to establish a difference between good and poor mappers in navigation performance, this environment may not have provided a stringent test for observing skill differences. In Experiment 2 we found that the number of trials required by the two groups to learn the Rand map did not differ, although the good mappers did excel at learning the Australia map and the novel Brentwood environment. The failure to obtain a difference between groups on the Rand map occurred because several poor mappers learned the map relatively quickly. Thus, the Rand environment may not have been sufficiently challenging to produce differences between good and poor mappers.

Table 8

PERFORMANCE ON NAVIGATION TASKS
IN EXPERIMENTS 3 AND 5

Measure	Good Mappers	Poor Mappers	t-value
Normalized navigation time, Experiment 5	32.7	37.0	.83
Route distance, Experiment 5	66.2	68.5	1.89
Percent of subjects who erred in navigation, Experiment 3	25	50	

To examine this potential problem, we related navigation performance directly to ease of learning the Rand map. Since all subjects learned the map to a criterion of perfect recall, they all presumably had encoded the knowledge they needed to navigate effectively. However, subjects who required longer to learn the map may have had more difficulty accessing and using the spatial knowledge than subjects who learned the map relatively quickly. To test this possibility, we correlated across subjects the number of trials to criterion when learning the map with normalized navigation time and route length. The correlation with navigation time was reliable ($r = .45$, $p < .02$), while the correlation with route length was not ($r = .31$, ns). Thus, there is at best weak evidence that subjects who more readily acquire spatial knowledge also use that knowledge more effectively and accurately to navigate.

Another typical type of navigation requires the individual to navigate with the aid of an external map. While such navigation, unlike the navigation skill tested in this experiment, does not require memory retrieval of the requisite spatial knowledge, it does require that survey knowledge represented in two dimensions be used to make navigation decisions within the represented space. In this sense, the two navigation tasks are similar. We contrasted this type of navigation performance between the two mapper groups using data obtained from Experiment 3, in which subjects used a map to navigate (by driving) in a novel environment. In that experiment, subjects recorded the errors they made in following a specific route marked on the map. In addition to these data, subjects' responses to postnavigation questions indicated whether

they had navigated the route perfectly. Using these data sources, we noted whether or not each subject had erred during navigation. As the last row of Table 8 shows, twice as many poor mappers as good mappers erred during navigation. This difference approached significance, (x^2 (1) = 2.30, $p < .10$).

In sum, the navigation results from these two studies fail to establish firm differences in navigation skill between good and poor mappers. Like the results from the map-using tasks, this study suggests that good and poor cognitive mappers do not differ on tasks that require relatively simple retrieval of stored knowledge or manipulation of external spatial information.

VIII. GENERAL DISCUSSION AND CONCLUSIONS

At the outset, we defined cognitive mapping skill in terms of the accuracy of subjects' spatial representation of a familiar large-scale environment. We then investigated subjects' performance on a number of other tasks to develop a more detailed profile of the skill differences between good and poor mappers. Across the range of tasks we investigated, we identified the following distinguishing characteristics of skilled cognitive mappers.

1. Skilled cognitive mappers excel at encoding procedural knowledge from the environment when navigating. The results of Experiment 3 indicate that good mappers acquire more accurate knowledge when navigating in a novel environment. We have assumed here and elsewhere (Thorndyke & Hayes-Roth, 1980) that limited navigation experience in an environment leads to memory for the traversed routes (i.e., procedural knowledge). Such knowledge is optimal for judgments of orientation and route distance in the environment. The superiority of good mappers over poor mappers on these two tasks suggests that the good mappers use more accurate procedural knowledge to compute their judgments.

2. Skilled cognitive mappers excel at encoding survey knowledge from maps. Good mappers encode more information from a map on the first trial than do poor mappers, and they maintain this advantage throughout the course of learning. However, their rate of acquiring map information does not appear to be greater than that of poor mappers.

3. Skilled cognitive mappers excel at computing spatial judgments from stored knowledge. We found evidence for this conclusion in two

sources of data. First, our criterial task for distinguishing good from poor mappers required spatial judgments performed after thousands of exposures to the environment. It is unlikely, given such large numbers of exposures, that subjects differed substantially in the procedural knowledge available to them. Rather, good mappers excelled at abstracting survey knowledge from their navigation experiences and at computing the judgments from their stored knowledge. Second, in Experiment 2 good and poor mappers differed in the accuracy of their orientation judgments based on a memorized map. Since all subjects had an accurate survey representation of the space, differences in orientation judgments must have resulted from differences in the accuracy of the procedures that subjects used to compute their estimates.

On the other hand, poor mappers performed as well as good mappers on several tasks. These tasks relied primarily on perceptual processes and simple knowledge retrieval rather than on knowledge acquisition or mental computation. Good and poor mappers did not differ on Rand map and topographic map-using tasks. These tasks, involving place location or route finding, emphasize perceptual skills more than knowledge and memory. Similarly, good and poor mappers perform equivalently on navigation tasks, provided both groups utilize equally accurate spatial representations. To navigate, the individual must use perceptual cues from the world to maintain an indicator of the current position on either a memorized or an external map. Using this map, the navigator must then retrieve the direction of travel required to reach the destination. Poor mappers do not appear deficient in this skill. However, in real-world navigation situations in which the accuracy of a cognitive

map is uncontrolled, good mappers might navigate more effectively because of their use of a more accurate representation of the environment.

One of the more intriguing results of this study was the independence of subjects' performance on knowledge acquisition and on map-using tasks. Across subjects, we found no correlation between performance on tasks that required subjects to learn an environment, either from a map or from navigation, and tasks in which subjects used a map to identify landforms, locate landmarks, or trace routes. The reason for the independence of these two types of spatial processing activities may lie in the fundamental abilities required for their successful execution.

For example, subjects' success at acquiring knowledge from maps is predictable from their psychometrically defined visual memory ability (Thorndyke & Stasz, 1980). The visual memory construct represents an individual's ability to encode complex arrays of spatial information and to retain that information in memory. This ability varies markedly across individuals. Clearly, a large component of learning a map requires the encoding of the purely spatial configurations of information. Similarly, acquiring and using procedural knowledge requires the encoding of spatial information perceived during navigation and the subsequent "mental simulation" of those navigation experiences for computing spatial judgments, such as route distance estimation or orientation judgments. Since the performance of good mappers differs from that of poor mappers on these tasks, it is reasonable to hypothesize that good and poor mappers might differ in this ability. In fact, we have obtained evidence supporting this ability difference (Thorndyke & Goldin, 1981).

The ability to generate and manipulate visual images also seems to underlie performance on a number of the tasks we tested. In particular, when subjects must compute spatial judgments using survey knowledge, such as a memorized map, they must create and scan a mental image of the map from an imagined position above the map. To produce an orientation judgment, they must also translate an answer computed from a perspective above the environment to an angular response described from a horizontal perspective within the environment. The ability to create and manipulate images is measured psychometrically by the visualization and spatial orientation constructs. Considerable research has been devoted to individual differences in these abilities (e.g., McGee, 1979; Richardson, 1969; Snyder, 1972). Again, we have found that good mappers score better on tests of these abilities than poor mappers (Thorndyke & Goldin, 1981), just as they performed better on the tasks in this study that appear to require these componential skills.

Finally, differences in mapping skill may result from differences in the strategies subjects use to select, encode, and integrate spatial information. Thorndyke and Stasz (1980) found that good map learners studied map information systematically by segmenting the map into sections and studying one section at a time. In so doing, they focused their study efforts on map information not yet mastered. Poor learners, by comparison, studied haphazardly, unsystematically, and inefficiently. When navigation provides the source of spatial knowledge, differences in attentional focus may also influence learning rate. Some evidence suggests that focusing on symbolic labels for spatial features in the environment (e.g., street names, compass directions) and on logical or

sequential relationships (e.g., order and name of intersections) leads to highly accurate survey knowledge but poor knowledge of perceptual features. On the other hand, focusing on perceptual details (e.g., landmarks, features of intersections, local direction changes in streets and roads) leads to more accurate procedural knowledge but more slowly developed survey knowledge (Thorndyke, 1980). Whether poor mappers can be effectively taught to use more effective knowledge acquisition strategies remains an intriguing research question.

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